

## **Multibeam Mapping of the Uncertainty of the Seafloor in the Southern East China Sea**

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### **LONG-TERM GOALS**

The long-term goal of the Quantifying, Predicting and Exploiting Uncertainty DRI is to understand and exploit (if possible) the fundamental acoustic, oceanographic, bathymetric and geoacoustic uncertainties of the tactical naval environment, and demonstrate how they may be exploited tactically or strategically in an Exercise Area. Focussing on the seabed, our goals are to understand the fundamental tactical and strategic uncertainty of the bathymetric and geoacoustic environment, and develop methods for their representation, visualization, computation and manipulation in a manner consistent with models of sonar performance estimation and prediction.

### **OBJECTIVES**

The scientific objectives of the UNH team are:

1. Understand the sources and magnitudes of bathymetric and geoacoustic uncertainty in the Southern East China Sea Exercise Area, and their implications for acoustic modelling.
2. Develop a framework methodology for expression of user-relevant uncertainty in the bathymetric and geoacoustic context.
3. Develop appropriate representation/visualization techniques for the uncertainty models developed.
4. Provide continually updated “best available” estimates of bathymetry, backscatter and uncertainty models to the QPE technical group, consistent with data access limitations.

### **APPROACH**

Due to requirements for data control via a Limited Distribution statement, the work covered here was administratively split between grant N00014-08-1-0786 and contract N00014-08-M-0244. We describe here, for convenience, the approach and other details for both instruments.

Bathymetry and geoacoustic uncertainty are primary drivers in the acoustic propagation problem, defining one of the complex boundary conditions for the ocean waveguide. The roles of the two components can often be complementary, however, with bathymetry being very significant in areas of complex and steep relief, and geoacoustic uncertainty being significant in otherwise undistinguished ba-

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| 14. ABSTRACT<br><b>The long-term goal of the Quantifying, Predicting and Exploiting Uncertainty DRI is to understand and exploit (if possible) the fundamental acoustic, oceanographic, bathymetric and geoacoustic uncertainties of the tactical naval environment, and demonstrate how they may be exploited tactically or strategically in an Exercise Area. Focussing on the seabed, our goals are to understand the fundamental tactical and strategic uncertainty of the bathymetric and geoacoustic environment, and develop methods for their representation, visualization, computation and manipulation in a manner consistent with models of sonar performance estimation and prediction.</b>   |                                    |                                     |   |   |                                 |
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thymetric environments [Holland, 2006]. Both, however, are typically poorly sampled spatially and temporally in most tactical environments, although they can be well characterized when sampling is done. Understanding the variability of the unobserved, therefore, is critical to characterizing and exploiting the uncertainties that are significant for the tactical environment.

We approach the problem of fundamental bathymetric uncertainty by considering not the best possible bathymetry, but the bathymetry more likely to be available in a tactical situation where the modeling uncertainty is likely to be dominant. The vast majority of the world is mapped, at least in shallower water, with at best sparse soundings from a single-beam Echosounder. While we might make very high resolution maps of a particular target area, therefore, it is unrealistic to believe that this is likely possible for most situations. We have therefore taken modern high resolution MBES data and subsampled to more typical data densities, with the intent of calibrating our estimates of uncertainty from such data, and groundtruthing the *ab initio* estimate of uncertainty for our target area (using methods such as [Calder, 2006; Goff *et al.*, 2006]). In addition to providing input to estimates of the effects of bathymetric uncertainty, this scheme will allow us to determine the likely observability *in situ* of small, but potentially significant features (e.g., sand ridges [Liu *et al.*, 2000]) that might be present.

Information about important geoacoustic features, e.g., mud volcanoes or pock-marks [Yin *et al.*, 2003] (which are often associated with the presence of gas in the sediment, and the effusion of gas into the watercolumn), is even less well defined. Although we might glean some information about their presence from backscatter measurements and watercolumn data in a specific case, we will likely never have sufficient information to fully characterize them deterministically. We hypothesize, however, that a stochastic description of their mean effect might be effective in an uncertainty-augmented acoustic propagation scheme. We are therefore developing suitable spatial statistical models, based on the inferred acoustic groundtruth from backscatter and other pilot-program observations, to allow for such incorporation, and the visualization and representation techniques to allow them to be fully exploited.

The sources for all of our research under this program are high-density bathymetric, acoustic backscatter and watercolumn observations; these data have also proved essential for planning and development of the field experiment. The opportunity for new data collection being limited, we have assembled the dataset from public and government databases, and continue to add new data as observations are made during the pilot and field experiments. Coarse bathymetric products suitable for public release can then be made as required and published on the QPE website, and specialized products are made on request; we continue to maintain a geospatial database for the data, including visualization products. Current limitations on distribution of data from some sources mandate that high-resolution bathymetric and backscatter products cannot be publicly distributed. These data are maintained separately, and products are released only as required (to qualified recipients).

## WORK COMPLETED

**Database Assembly & Product Creation:** We have continued to maintain the database of bathymetric data for the target area, adding to it as new data has become available from the pilot experiment. We have provided the publicly available portion of this database to a number of DRI participants in a variety of formats, as requested by the PIs. We have also supported the planning process for the DRI's Intensive Observation Period (IOP) using limited distribution sections of the database, where the PIs were appropriately qualified. This has included generation of custom backscatter angular dependence curves, evaluation of mooring locations, and assessment of morphological complexity in the targeted

exercise areas, as well as refinement of the specific locations for these areas. We continue to pursue release authorization for the limited distribution data from the appropriate authorities.

**Bathymetric Uncertainty Calibration:** We have constructed initial estimates of uncertainty of the database bathymetry, including compensation for refraction effects evident in some of the data, most likely due to the effects of the Kuroshio current in the target areas. We have also begun the process of estimating the uncertainty that would be predicted from classical databases in order to cross-validate out best estimates, and provide a bounding estimate for the likely uncertainty of the publicly available bathymetry.

**Unobserved Geoacoustic Uncertainty:** We have extracted, processed and georeferenced the dual-frequency EK500 data from the pilot cruise, providing bathymetric measurements (for along-track geomorphological analysis) and full watercolumn data in a variety of different formats for distribution to the other PIs. This data provides calibrated backscatter measurements for the bottom reflectivity of the surface sediments in addition to volume scattering in the watercolumn. We have begun the process of matching this against our current databases for cross-calibration purposes, and to support analysis and detection of the potential for geoacoustically active sources in the target areas.

**Spatial Models for Unobserved Variability:** We have considerably enhanced the bathymetric portion of the spatial point process model describing potential for unseen objects to affect the bathymetric environment, leading to a stochastic model that predicts the plausible effects of such objects on variables of interest (e.g., mean waveguide depth) over an area or trajectory. We have also shown that the computational framework is very flexible in practice, and can easily adapt to complex descriptions of local constraints on variables, even if only empirical observations are available.

## RESULTS

Due to the use of Limited Distribution data in the development of some of the following results, details are intentionally omitted here; full details are available in the “Distribution D” version of this report.

**Database Assembly & Product Creation:** Detailed depictions of the highest resolution data available from the database, presented in an interactive 3D visualization environment have been combined with experimental acoustic, physical oceanographic and geoacoustic constraints to allow for planning of the IOP. Figure 1 shows an example of the quality of data available from the underlying database, including planned observation points from the IOP, and estimated backscatter measurements and fitted theoretical models (using the method of [Fonseca & Mayer, 2007]). The backscatter model’s predictions of sediment type were used to plan where to locate instruments during the IOP.

**Bathymetric Uncertainty Calibration:** We focus on target area 4, at the southeast of the main exercise area for the IOP. The area is covered by both high- and low-frequency sonars, which we combine to generate the composite bathymetry at a resolution of 15m in a mean depth of [-]m (Figure 2(a)). The internal uncertainty of the data, Figure 2(b), shows uncertainties on the order of [-]m (rms), 99% of the time, but underestimates the magnitude of the effects where the two data sources are combined, and fails to assess vertical uncertainties associated with the survey vessels that apply everywhere. Refraction effects in the high-frequency sonar cause significantly higher observed depth variability, which we assess by comparison of the sources considered separately (Figure 3(a)). Identification of the mean offset allows us to assess a vertical mean uncertainty of [-]m, which we combine with the internal uncertainty and an estimate of static vertical uncertainty to form the absolute uncertainty esti-

mate for the area, Figure 3(b). This leads to an asymmetric uncertainty estimate for the bathymetry, since the refraction effect is a unidirectional bias in this case. Internal estimates of uncertainty for areas using the high-frequency sonar elsewhere in the exercise area must be adjusted equivalently in order to give useful estimates of effective uncertainty. Whether to use internal or absolute uncertainty estimates depends on the user and application; our research provides both.

**Unobserved Geoacoustic Uncertainty:** Analysis of the EK500 watercolumn data from the pilot project allows us to build fully georeferenced data assemblies showing this data in the context of the larger bathymetry, within an interactive 3D visualization environment, Figure 4. The observed depths correlate well with the existing database. This data has been used for planning of the IOP, assessment of geoacoustic sources in the area, and quality assurance of the instrument suite. The dataset shows evidence of a number of watercolumn and seafloor features that might be of significance, although whether these are natural, or the result of congregations of pelagic fauna is still to be determined.

**Spatial Models for Unobserved Variability:** We have extended our previous non-stationary Poisson spatial point process models for unobserved bathymetry to allow them to be used in 2D configuration, and to be calibrated for environmental factors. Figure 5 shows an example of this where the color coding shows the effective risk involved in traversing each area as assessed for surface ships of different configurations. This is a direct analogy for effective waveguide depth for acoustical models, and allows for summaries to be built for any subsequent configuration of trajectory (resp. raypath) through the area. This model extends the ideas of uncertainty from a simple description of the variability of an observed parameter (e.g., depth, transmission loss) into a unified description of effective risk on a scale that is designed to be readily interpreted by end-users.

## IMPACT/APPLICATIONS

Availability of high-resolution bathymetric uncertainty estimates provides for appropriate interpretation of the available database when used in context for either planning or analysis of acoustic, oceanographic or geoacoustic observations. Integration of watercolumn observations within a single, consistent georeferenced framework allows for coherent contextual analysis, potentially improving insight into the causes of observed phenomena. Watercolumn data may potentially provide useful background information for interpreting IOP observations, cross-calibrating backscatter measurements and derived products, and investigating the (stochastic) potential for active geoacoustic features. Many descriptions of uncertainty are highly technical in nature, and often extremely difficult to communicate outwith the academic community. Our approach here of converting the observation, modeling and environmental uncertainties into a uniform scale of risk may in the future provide a simpler means to achieve the goal of a simple end-user summary of uncertainty.

## RELATED PROJECTS

None

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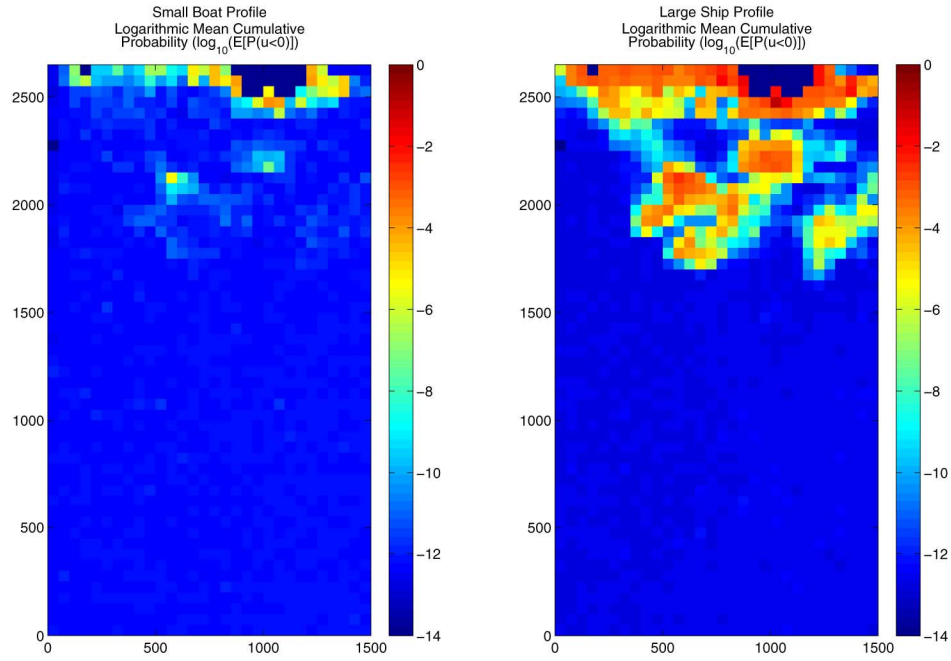
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Figures Available in  
Distribution D version of this report

***Figure 1-4: These figures describe results derived from, or combined with, the Limited Distribution data, and cannot be reproduced in this document; full details are available in the “Distribution D” version of this report.***



***Figure 5: Example of expected risk associated with traversal of an area. Each cell is color-coded with the expected risk (on a logarithmic scale) for transiting the cell; the two examples are for different ship configurations. A composite risk assessment like this combines observation, modeling and environmental factors in many different forms into a single, coherent description of risk with the intent of explaining these risks in a unified manner to the end-user of the data.***